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Short Communication

A web-based tool to engage stakeholders in informing research planning for future decisions on emerging materials

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HIGHLIGHTS

- A web-based, interactive decision support tool was piloted for emerging materials.
- The tool (CEAWeb) was based on an established approach to prioritize research gaps.
- CEAWeb facilitates multi-stakeholder prioritization of research gaps.
- We provide recommendations for future versions and applications of CEAWeb.

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ABSTRACT

Prioritizing and assessing risks associated with chemicals, industrial materials, or emerging technologies is a complex problem that benefits from the involvement of multiple stakeholder groups. For example, in the case of engineered nanomaterials (ENMs), scientific uncertainties exist that hamper environmental, health, and safety (EHS) assessments. Therefore, alternative approaches to standard EHS assessment methods have gained increased attention. The objective of this paper is to describe the application of a web-based, interactive decision support tool developed by the U.S. Environmental Protection Agency (U.S. EPA) in a pilot study on ENMs. The piloted tool implements U.S. EPA's comprehensive environmental assessment (CEA) approach to prioritize research gaps. When pursued, such research priorities can result in data that subsequently improve the scientific robustness of risk assessments and inform future risk management decisions. Pilot results suggest that the tool was useful in facilitating multi-stakeholder prioritization of research gaps. Results also provide potential improvements for subsequent applications. The outcomes of future CEAWeb applications with larger stakeholder groups may inform the development of funding opportunities for emerging materials across the scientific community (e.g., National Science Foundation Science to Achieve Results [STAR] grants, National Institutes of Health Requests for Proposals).

Abbreviations: CEA, comprehensive environmental assessment; CEAWeb, CEA web interface; CEAPrioritize, CEA spreadsheet tool; ENM, engineered nanomaterials; E–RRF, element–risk relevance factor pair; HERO, Health and Environment Research Online; MCDA, multi-criteria decision analysis; MWCNTs, multiwalled carbon nanotubes.

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1. Introduction

1.1. Decision support approaches for emerging materials

Data gaps and scientific uncertainties associated with the behavior of emerging materials can limit our ability to quantify environmental health and safety (EHS) risks, resulting in inadequate information for risk managers. Risk management of emerging materials, such as engineered nanomaterials (ENMs), can benefit from innovative methods that: 1) incorporate various aspects of EHS risks, 2) identify sources of uncertainty and data gaps, and 3) consider stakeholder preferences. To demonstrate the development and pilot testing of one such innovative method, this short communication focuses on ENMs as an example class of emerging materials.

In the case of ENMs, researchers have begun to develop assessment tools and approaches that may help guide decisions about the prioritization of research gaps, preferred methods of ENM synthesis, or identification of ENMs that present the "most" or "least" potential risk based on stakeholder values (e.g., Linkov and Seager, 2011; Tervonen et al., 2009; U.S. EPA, 2012b). Many of these methods incorporate components (e.g., product life cycle framework, exposure and hazard considerations, prioritization) recognized as important for moving toward risk analyses and subsequent risk management of ENM (NRC, 2012; OECD, 2012). Yet as noted in a recent review, available approaches for ENM risk analysis often focus on potential risks in occupational settings and have generally not been applied to a wide variety of ENM (Grieger et al., 2012). Both of these shortcomings suggest that the field would benefit from an approach to more quickly evaluate multiple ENM-types in the context of future environmental (including occupational) risk analyses and risk management. Moreover, recent guidance from the National Research Council and others notes the importance of structured approaches to 1) better connect the identification of research gaps with future assessment efforts, and 2) engage stakeholders throughout the risk assessment process (Abt et al., 2010; NRC, 2011; U.S. GAO, 2013). To address these gaps in current approaches (i.e., relatively rapid evaluation, inclusion of environmental and occupational data, connection of research gaps to future assessments, stakeholder engagement) a pilot tool was developed based on an existing approach, comprehensive environmental assessment (CEA).

1.2. The CEA approach

The U.S. EPA CEA approach facilitates a *process* to collect available information within a *framework* and consider expert stakeholder input in decision making on complex EHS problems (Powers et al., 2012). CEA aims to (i) link research planning, risk assessment, and risk management; (ii) structure and integrate complex information from multiple analytical techniques and approaches (e.g., LCA, risk assessment); (iii) engage diverse perspectives to inform near-term or long-term risk management efforts; and (iv) support iterative risk assessment approaches and adaptive risk management through prioritization efforts (Powers et al., 2012). While other risk-based approaches (e.g., life cycle assessment [LCA], human health risk assessment [HHRA]) or decision support approaches (e.g., MCDA, expert elicitation) can support any one of these objectives, CEA adds an approach to manage information from existing assessment and decision support tools (i.e., a meta-assessment) to the decision maker's tool box (Powers et al., 2012). U.S. EPA has recently applied CEA to several types of ENM (U.S. EPA, 2010, 2012a,b). The core components of each CEA application included (1) draft case study documents that use the CEA framework (conceptualized here in Fig. 1)

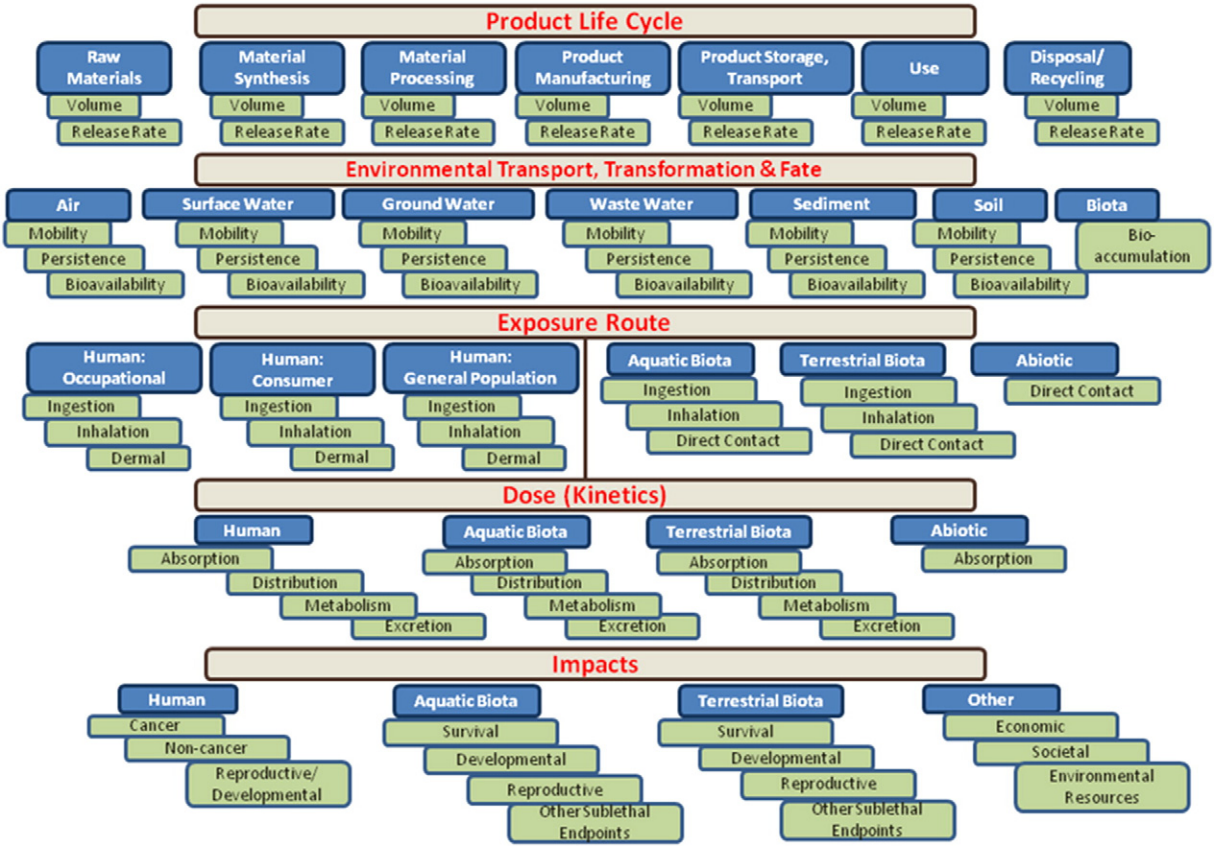

Fig. 1. Detailed CEA framework that provides more granularity to the previously developed framework (see U.S. EPA, 2012a,b). Source RTI International (2012).

to organize compiled information on the ENM of focus (e.g., multiwalled carbon nanotubes [MWCNTs]), and (2) the engagement of expert stakeholders, a large portion of which involved face-to-face interactions. The first component helps to ensure that information pertinent to a wide range of domains (e.g., product life cycle, exposure in human or ecological populations, economic or social impacts) is conveyed to expert stakeholders. The CEA case study documents thereby support the consideration of issues (e.g., aggregate and cumulative exposures, environmental justice) that are less frequently included in other assessment approaches (e.g., LCA, HHRA) during the structured stakeholder engagement within CEA.

1.3. CEA web interface (CEAWeb)

Active stakeholder involvement is important to inform EHS decision making (Jones, 2009; NRC, 2008); however, time, budget, and environmental considerations can impede face-to-face stakeholder interactions. To address these challenges, a web-based decision support tool was developed ("CEAWeb") that employs a collective judgment method to gather expert input; this tool was evaluated during a pilot study on MWCNTs in flame-retardant coatings applied to upholstery textiles. Assumptions that underlie this pilot work include the following. First, that a relatively small group of expert stakeholders can demonstrate the utility of a tool intended to be used with a larger stakeholder group. Second, that limiting interaction between expert stakeholders to the review of written comments and data representing the group's collective response would more clearly show the potential value and limitations of a web-based stakeholder engagement approach compared to face-to-face engagement approaches.

The pilot resulted in two outcomes: 1) a demonstration of this web-based decision support tool to facilitate iterative stakeholder engagement in the CEA approach, and 2) a set of example research priorities identified by expert participants using the tool. The research priorities identified through the web-enabled CEA process are briefly compared here to priorities identified through a similar CEA process that also included a more traditional face-to-face workshop.

2. Materials and methods

A web-based prioritization tool, CEAWeb, was developed by U.S. EPA as described in the supplementary material. CEAWeb is based on a spreadsheet-tool, CEAPrioritize (RTI International, 2012). CEAPrioritize was developed[1] and used in a parallel prioritization effort that included two rounds of remote prioritization (i.e., experts accessed and completed the tool without meeting), followed by a third prioritization round during a face-to-face workshop independently conducted by RTI International and funded by U.S. EPA (RTI International, 2012). Both prioritization processes (remote prioritization only [CEAWeb] and remote prioritization plus face-to-face [CEAPrioritize]) used the same draft CEA case study document on MWCNTs (hereafter MWCNT draft case study document) to provide experts with common background information on MWCNTs (U.S. EPA, 2012a). Similarly, in both prioritization processes participants with comparable distributions of expertise and sector perspectives were recruited; however, limited budget resources in the CEAWeb pilot restricted the number of participants, resulting in fewer areas of expertise in the pilot (CEAWeb: 8 and 6 participants in Rounds 1 and 2, respectively; CEAPrioritize: 32, 28, and 13 participants in Rounds 1, 2 and 3, respectively). Approximately half of the participants selected to pilot CEAWeb were also participants in the prioritization process that utilized CEAPrioritize in conjunction with the RTI International face-to-face workshop; this allowed for direct comparison of the CEAPrioritize plus face-to-face and CEAWeb in ranking research priorities. Though not large enough for statistical evaluations, the objective of this comparison was to better understand the implications of using CEAWeb in lieu of face-to-face interaction when identifying research priorities. CEAWeb can be used to inform research planning decisions for any material or group of materials; however, it is applied here to MWCNTs as a test case. For details on selecting the test case see U.S. EPA (2012a).

To pilot the CEAWeb tool, RTI International, a contractor for U.S. EPA, independently selected scientific experts based on their areas of expertise (e.g., chemistry, fate and transport, toxicology) and sector areas (e.g., academia, industry, government). The overall goal in the selection process was to include a diverse range of both technical and sector perspectives in the pilot (see the supplementary material for additional details). Participants used CEAWeb, hosted by U.S. EPA on a secure online platform, to rate research areas based on the CEA framework.

Participants accessed the CEAWeb home page on the U.S. EPA's Health & Environment Research Online (HERO) website (http://hero.epa.gov/). The home page provided background information on CEA and the web-based pilot, along with links to the MWCNT draft case study document and the MWCNT-specific portion of the prioritization tool (CEAWeb—MWCNT). After accessing the home page participants were instructed to watch an introductory webinar on the prioritization process and review the MWCNT draft case study document for background information (U.S. EPA, 2012a). A user's guide with step-by-step instructions for completing CEAWeb was also made available for participants. For this pilot, two rounds of prioritization were completed with CEAWeb.

In each round of prioritization experts rated research areas across a detailed version (Fig. 1) of the existing CEA framework (Powers et al., 2012) according to their level of "Importance" to risk assessment efforts and "Confidence" in the availability and utility of current information to

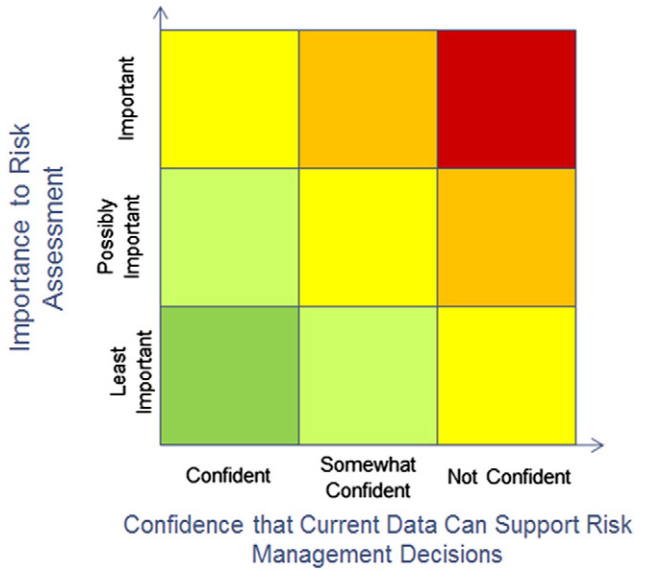

Fig. 2. Prioritization matrix. In the prioritization process employed in the CEAWeb pilot, research areas (i.e., E–RRF pairs in Fig. 1) that experts rated as "Important" to risk assessment and "Not Confident" that existing data can support risk management decisions were deemed high priority research areas (RTI International, 2012). Colors in the figure indicate the priority level associated with each combination of importance/confidence (i.e., red denotes the highest priority for research, followed by orange, yellow and green, respectively).

[1] The software tool was developed using Microsoft Excel by RTI International in an EPA-funded project.

support risk management decisions (Fig. 2). Specifically, participants rated research areas in the form of "Element–Risk Relevance Factor" (E–RRF) pairs within the detailed CEA framework (e.g., "Air" is an element associated with the risk relevance factor "Mobility" within environmental transport, transformation, and fate in the CEA framework, see Fig. 1). Each step that participants carried out to complete the rating process is listed in the supplementary material. Briefly, each participant rated each element based on its importance to consider in future risk assessments of MWCNTs in flame-retardant textiles (i.e., ratings were "Important", "Possibly Important" or "Least Important"). For those elements that a participant rated as "Important" they were asked to rate the element paired with its respective RRFs (Fig. 1) based on the same scale of importance. They also rated each E–RRF on their level of confidence in the availability and utility of current data to support future risk management decisions for MWCNTs in flame retardant textiles (i.e., confidence ratings were "Confident", "Somewhat Confident" and "Not Confident") (Fig. A.1). Prior to completing each prioritization round, participants were instructed to review their ratings prior to submitting their final answers.

After each round of prioritization, all participant ratings were compiled and tallied for each E–RRF. Each E–RRF pair was then assigned a bin in the prioritization matrix (Fig. 2) based on the most frequently selected rating for "Importance" and "Confidence". Those areas (i.e., E–RRF pairs) that experts most commonly rated as both most important to risk assessment and had the least confidence in the data to support risk management decisions (i.e., red bin in Fig. 2) were then identified as "high priority research areas". See the supplementary material for more details related to the methodologies and terms used in the prioritization process.

Participants were instructed to complete the first round of prioritization using CEAWeb (Round 1), view and compare the results of the group with their own by using a series of bar charts and tables, and then complete the second and final prioritization round using CEAWeb (Round 2). The output from Round 2 formed the final results generated from the pilot prioritization process. Participant feedback on the prioritization process and the use of the CEAWeb was also solicited.

3. Results

3.1. Demonstration of CEA web-based stakeholder engagement

CEAWeb was developed to facilitate the prioritization of research gaps in areas where new data could make future risk assessments more scientifically robust, and subsequently inform risk management decisions involving emerging materials. Experts in the ENM field with diverse sector and technical perspectives agreed to participate in a pilot study using CEAWeb with a specific material, MWCNT (CEAWeb—MWCNT, shown in Fig. 3).

In total, eight participants utilized CEAWeb—MWCNT to complete the first prioritization round (Round 1) and six participants completed the second prioritization round (Round 2)[2]; four of the participants who completed Round 2 also participated in the prioritization process using CEAPrioritize and a face-to-face workshop. In the case of the CEAWeb pilot, Rounds 1 and 2 results (Tables A.2 and A.3) were conveyed to participants using a series of bar charts and tables (e.g., Fig. A.2) to allow the experts to become familiar with how other experts perceive research priorities without face-to-face discussion. The primary outcome of this pilot study was the demonstration of how a web-based tool can facilitate the iterative engagement of expert stakeholders to prioritize research efforts.

[2] The initial number of participants was small due to resource constraints and the pilot nature of this project. Two participants did not complete the second round due to competing priorities. See the supplementary material for greater detail on participant selection.

Expert reviews of CEAWeb were generally positive, with mostly positive or neutral feedback to all ten questions related to the tool posed to reviewers (Table 1). With regard to CEAWeb as a tool, the experts identified website accessibility and download speed consistency as two areas for improvement. With regard to the prioritization process, the experts had differing opinions on areas for improvement. For example, some experts suggested reducing the number of areas (e.g., E–RRFs pairs) to rate during each round of prioritization, while others noted that the E–RRF pairs included in the current version of the tool allowed them to more easily consider information outside their field of expertise. Participants also identified reducing the amount of time required to complete the prioritization process as another areafor improvement, including (1) decreasing the total number of prioritization rounds, (2) allowing responses in one area to be applied to another, and (3) retaining data from one round to the next so that participants did not need to re-enter responses. In addition, some experts noted that greater interaction with other participants between rounds would improve the prioritization results. Finally, one expert noted the importance of identifying inter-relationships between different areas of the CEA framework (e.g., "Air–Mobility" relates to "Human Occupational-Inhalation"), something that is not currently supported by CEAWeb.

3.2. Research areas identified through piloting CEAWeb

Research priorities obtained in this pilot of CEAWeb—MWCNT were in general agreement with those identified using CEAPrioritize and a face-to-face workshop. As shown in Fig. 4, most priorities from both processes (i.e., with and without a face-to-face meeting) relate to MWCNT release across the product life cycle and human exposure or health impacts (Fig. 4; Supplementary Tables A.3 and A.4). Yet, several key differences were observed. For example, experts using CEAWeb alone identified a smaller number of priorities (13) compared to those that participated in a face-to-face discussion (24). Experts using CEAWeb also tended to have higher importance and confidence ratings for research priorities compared to those participating in the face-to-face workshop (Fig. 4). Additionally, "other" impacts (i.e., social, economic, environmental resources) identified as priorities through face-to-face discussion, were not identified by experts through the exclusive use of CEAWeb. Experts also provided specific research questions for priority research areas (Table A.5). These example research questions for MWCNTs demonstrate how CEAWeb can facilitate engaging stakeholders in moving from identifying broad research areas to informing more detailed research planning.

4. Discussion and conclusions

The successful pilot of CEAWeb to prioritize specific ENM research needs demonstrates several advantages compared to non-web based prioritization tools (e.g., face-to-face workshops, desktop software tools). Previous efforts to engage experts in identifying and/or prioritizing research gaps for ENM have relied primarily on expert elicitation (e.g., Morgan, 2005; Wardak et al., 2008) or workshops and committee discussion (e.g., NNI, 2011; NRC, 2012). CEAWeb builds on these efforts by incorporating a structured methodology to ensure that each expert has equal input in the outcome (i.e., identified research priorities) and thus avoid outcomes that may represent the perspective of some technical disciplines or sectors more than others. In addition, previous efforts generally rely on face-to-face interaction, which can limit the number of individuals involved in the process due to time, travel, budget, or other constraints. Specific advantages of CEAWeb include:

- supporting virtual interactions among, theoretically, an unlimited number of participants;
- allowing participants to manage their time individually, thereby increasing the likelihood, and potentially, the quality of participation by increasing convenience;

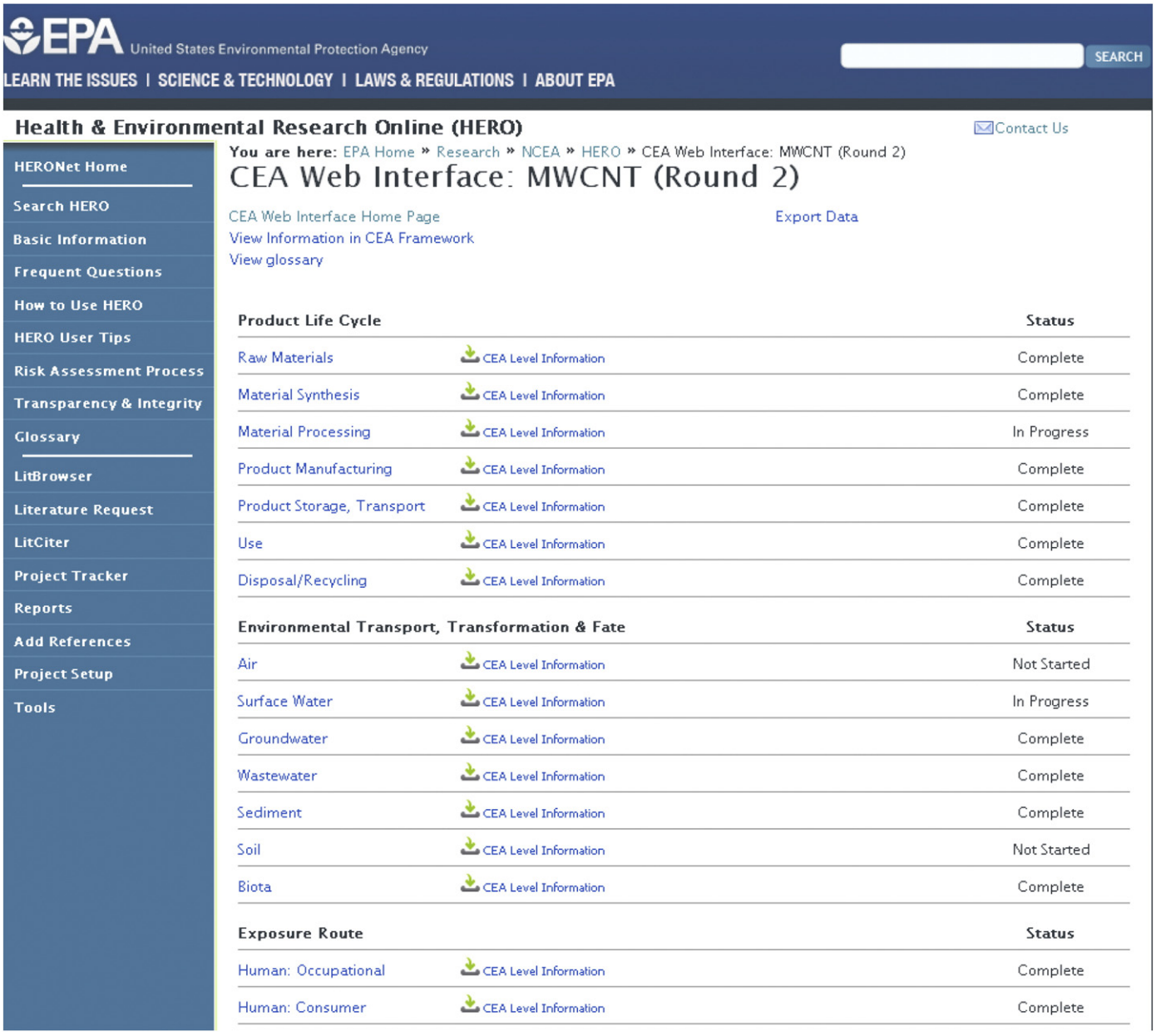

Fig. 3. CEAWeb—MWCNTs. The portion of CEAWeb that participants used to rate research areas for MWCNTs.

- providing a dynamic interface so that content is based on the user's responses (e.g., status updates, content-specific warning messages for incomplete responses, final check prior to submission [data not shown]);
- increasing stakeholder input on research planning for a variety of chemicals or materials since multiple iterations of the tool could be run simultaneously (i.e., multiple groups of experts could evaluate different chemicals or materials at once); and
- promoting real-time feedback on the tool by the user community, allowing for continual improvement as new versions are produced.

Nevertheless, several features/functions were identified for development in subsequent versions of CEAWeb (see Table 1 and supplementary material), including:

- employing a pre-prioritization step in which participants take part in a structured discussion to agree on a subset of areas in the CEA framework to focus on, which would narrow the scope of prioritization for a given chemical or material;
- providing background information on E–RRFs to clarify the types of considerations in each (e.g., listing potential abiotic resources affected by exposure to a material to clarify "Abiotic-Direct Contact" under "Exposure Route" [Fig. 1B]);
- facilitating the identification of inter-relationships between areas of the CEA framework;
- allowing structured discussions of results (e.g., use of social networking mechanisms) and continuing to improve the user experience;
- presenting results in terms of the variation of responses in addition to providing an overall group rating;
- emphasizing how results will be used to inform research planning to encourage scrutiny of initial group results; and
- providing dynamic access to background information by directly linking to other existing tools and databases to use as reference material (e.g.,

http://webnet.oecd.org/NanoMaterials, http://icon.rice.edu/report.cfm) in lieu of a static draft case study document.

Results of this study show that research priorities identified by engaging stakeholders using a web-based tool are generally similar to those identified through a process that includes an additional face-to-face component. Notably, similarities in results may stem, in part, from 1) expert stakeholders in both processes reviewed the same background material (i.e., U.S. EPA, 2012a), and 2) some experts participated in both processes. While these factors combined with a small sample size prevent validating any assertions statistically, the results suggest that with some modifications to facilitate user interactions in CEAWeb, comparable results could be achieved using the web-based tool alone. Future efforts could build on these results by developing

Table 1
Summarized responses from experts participating in CEAWeb pilot study. The number of responses authors identified as "Generally Positive", "Neutral", or "Generally Negative" (Columns) is denoted for each question participants responded to in the CEAWeb pilot (rows). Gray shading denotes the column with the majority of responses. In instances of a tie both columns are shaded gray in the appropriate row. Full responses and their categorization as "positive," "negative," or "neutral" are shown in the supplementary material.

Question	Responses from participants			
	Generally positive (No.)	Neutral (No.)	Generally negative (No.)	Summarized feedback
1. Do you have specific suggestions for additional information that would be helpful to include on the CEA web interface home page? Alternatively, is there information that could be removed from the page?	3	1	2	• Improve CEA website interface (speed, password resets). Add dates after milestones • Instructions were clear and helpful • Case study section of webpage is crowded. • Simplify right–side by using collapsible categories of information • Previous case study documents do not need to be directly accessible
2. Did you refer to the user guide prior to accessing the web interface? If so, do you have specific suggestions for additional information to include in the CEA web interface wser guide document?[a,b]	5	1	2	• Information is useful & necessary but after the first round, the web interface is self–explanatory/ easy to use • Move step–by–step instructions (Section 3) to front of user guide, with full document as a resource • Easy to miss where the user guide is on the web page, one has to scroll down too far to find it
3. Do you have specific suggestions that could improve the CEA web interface: MWCNT page (e.g., ways to access the draft case study document, selection of elements, accessing the glossary)[c]	4	1	3	• CEA web interface: MWCNT is a very practicable tool, good access to documents and glossary • Decrease download time for portion of documents used as reference for each element • The case study is also listed too far down on the right side; move it front and center on the CEA website. • Consider only one round of rating; participant was more likely to select "Possibly Important" to follow group/ avoid selecting IFs • Don't clear responses from the 1st Round • Allow information to be copied from one portion of rating process to another (e.g., selecting similar factors that might influence risk of persistence in waste water and ground water)
4. Do you have specific suggestions to improve the format or usability of pages that allow you to rate elements and element–risk–relevance factor pairs, as well as select influential factors?[d,e]	5	0	4	• Compared to the non–web based approach, paring process seemed to move smoothly. • Particularly like easy access to the part of the case study that was relevant to a given set of questions. • Rating process needs to facilitate identifying inter–relationships between areas of the framework • The selection of the influential factors is not easy, because they are not always relevant to the elements in question. Allow Round 1 responses to be revised in Round 2 rather than starting over • Results need to be more clearly presented on Home Page • The outcome of the prioritization process is not intuitive
5. On a scale of 1 to 10, please rate how straightforward and easy the CEA web interface as a whole was to use in this prioritization process (1 = very difficult, 10 = extremely straightforward & easy). For any rating below 10, please provide specific improvements that would change your rating[f,g].	6	0	4	• As compared to other tools, the CEA Web Interface is very straightforward and practicable. • Reasonably easy to click through the boxes. • Website was much easier to fill out the influential factors since they are all on one screen; it was much easier to scroll down a web page than across a complex Excel spreadsheet. • Warning boxes became annoying after the first time (particularly for responses that weren't required) • Rating process needs to better distinguish between having confidence that something isn't important, so not much info is required versus when something is important and requires much more information (detail) and thus should be retained for further analysis • Reduce amount of introductory material & information on home page • Reduce time to complete rating process • Website speed needs to be consistently high

(continued on next page)

Table 1 (*continued*)

Question	Responses from participants			
	Generally positive (No.)	Neutral (No.)	Generally negative (No.)	Summarized feedback
6. On a scale of 1 to 10, please rate how the CEA web interface compares to using a spreadsheet tool (e.g., in Microsoft Excel) to conduct a rating process (1 = no difference between a spreadsheet and the Web Interface, 10 = using a spreadsheet is completely different than the web interface). Please briefly explain your rating by specifying whether the difference, or lack thereof, is preferable[h,i]	5	0	3	• It is quite different from the other tools, & much preferred. • Some parts which were quite different in ways that were better and worse. • Web interface is more suitable for working in influential factors and pairing processes. • Could go from one element to the next via different web pages instead of having all of them for a particular section on the same page. • Reviewing answers before submission seemed also easier in web based approach. • Pare down information to review & rate to improve confidence in rating • Discussion with diverse subject matter colleagues is critical • Consider enabling information from one area of rating process to be copied over to another portion (e.g., selecting similar factors that might influence risk of persistence in waste water and ground water) • Consider enabling rating on a local copy and transferring data to website for instances when an internet connection isn't available • Web tool is much more preferable than Excel tool for
7. Are there additional elements or risk relevance factors that would be beneficial to include in the detailed CEA framework for future applications of this approach to other chemicals, materials, or technologies?[j]	3	1	3	• Reduce number of elements & risk relevance factors and allow more identification of the interactions between pairs • Approach is applicable to other materials; biomaterials in biomedical & industrial sectors might be areas to apply the approach • Revise "inhalation for aquatic organisms" • Include links to literature reviews of CNTs
8. Did you find that including MWCNT–specific influential factors allowed you to add more detail to explain what could be important to research about the areas of the CEA you prioritized? Do you have specific suggestions about how the influential factor portion of the prioritization process could be improved, or about additional influential factors that would be beneficial to include?[k]	4	1	3	• Greater granularity is needed so that factors aren't considered in abstract • Adapt list of influential factors for each specific element • Having a list of factors to consider provides a quick overview of points to think of in prioritizing • Bio–physico–chemical variables captured in MWCNT influential factors capture the most relevant ones • Influential factors added more detail in some cases but added to time required to complete process • Influential factors didn't seem to influence the outcome • Remove influential factors to reduce time to complete the process • Influential factors added a high degree of granularity • Influential factors prompted consideration of angles that a participant wouldn't have thought of • Addition of influential factors didn't increase detail the in responses
9. Are the results of each prioritization round clearly conveyed? Do you have specific suggestions for improving how results are reported?	4	0	2	• Results were clearly presented • Bar graphs are not particularly informative • Focusing analyses on variation in responses would more useful • Reviewing results was time consuming but information was useful • Figures appeared somewhat crowded and confusing • Providing overall summary before detailed answers facilitated finding detail on particular elements of interest • Decrease sizes of colored boxes and increase font size within boxes to improve presentation of results

Table 1 (*continued*)

Question	Responses from participants			
	Generally positive (No.)	Neutral (No.)	Generally negative (No.)	Summarized feedback
10. Did you change your responses in Round 2 of prioritization after reviewing the results of Round 1 of prioritization? Please briefly explain why or why not?	1	4	1	• Responses changed somewhat but the most useful activity is discussion with experts in other subject matters • Recommend reducing number of rounds • Recommend using just one round. The first response is most likely the correct response. • Responses in the second (or third) rounds are not developed with as much focus and rigor as the first time around. • Re–assessed opinion, went back to background information, and changed response in a few instances when Round 1 response differed completely from the group • Little to no change in responses since initial responses were based on literature and discussion with experts in workshop • Changed some responses from Round 1 to 2, particularly those where the rest of the group rated an element differently • Moved rating closer to consensus rating if convinced by "Why" responses of others • In–person meeting strongly influenced second round responses • Did not change responses in areas of own expertise, but was informed by others' responses and made minor changes in other areas
11. What are the top three detailed research questions that you feel should be prioritized to enable future comprehensive environmental assessments of MWCNT flame–retardant coatings applied to upholstery textiles, in support of risk–based decisions?	N/A[l]	N/A	N/A	See Supplementary Table 5.

[a]One participant responded "I did not refer to the user guide since I had previously completed the Excel version.", which is considered a neutral response.[b]Two participants responded with both positive and negative comments, which were marked in both columns.[c]Two participants responded with both positive and negative comments, which were marked in both columns.[d]One participant had a positive response for element and element–risk-relevance factor pairs but a negative response for influential factors; the response is documented in both the positive and negative columns here.[e]Three participants responded with both positive and negative comments, which were marked in both columns.[f]One participant rated the web tool as "6" or "7" indicating a positive interaction, but suggested aspects of the rating process itself could be improved; thus, the response is reflected in both the positive and negative columns here.[g]Four participants responded with both positive and negative comments, which were marked in both columns.[h]Two participants responded with both positive and negative comments, which were marked in both columns.[i]Another participant responding to question 6 indicated a fairly neutral response (i.e., there were aspects that the participant liked more about the web tool than a spreadsheet, and others they preferred about a spreadsheet); thus the response is counted in both the positive and negative columns here.[j]One participant responded with both positive and negative comments, which were marked in both columns.[k]Two participants responded with both positive and negative comments, which were marked in both columns.[l]N/A = not applicable.

protocols specifically designed to measure how much face-to-face discussion alters the outcomes of stakeholder judgments. Outcomes of such studies could help optimize the collection of web-based stakeholder input, which may become increasingly necessary given the reality of limited resources with which to engage large numbers of subject matter experts with diverse sector perspectives (e.g., industry, academia, non-governmental organizations).

In addition to providing a foundation for future investigations comparing face-to-face and web-based engagement methods, results of this work inform comparisons of web-based and other electronic engagement tools (e.g., spreadsheets). Expert stakeholders who participated in both processes could directly compare between CEAWeb and the spreadsheet tool (CEAPrioritize) that provided a foundation for the web-based tool. Participant feedback suggests that CEAWeb represents an overall improvement from a spreadsheet tool (5 generally positive responses, 3 generally negative responses; Table 1, Question 6). Based on some specific comments (e.g., "It is quite different from the other tools, & much preferred"), future applications of CEAWeb could not only reduce reliance on face-to-face interactions, but also facilitate increased participation compared to approaches using spreadsheets or other similar tools. Expert feedback on the pilot study for the CEAWeb will pave the way for more extensive use of a web-based process to enable the critical research planning and risk management needed to address ENMs and other emerging risks.

Future applications of CEAWeb with larger stakeholder groups can support the development of research plans for a variety of chemicals or materials that inform future risk assessments in a manner responsive to recent guidance (U.S. GAO, 2013). Information that emerges from future CEAWeb applications could be made publicly available via the internet and thus used to inform individuals developing research funding opportunities for ENM and other emerging materials throughout the scientific community (e.g., STAR grants, National Institutes of Health Request for Proposals). Indeed, a recent multi-stakeholder review of emerging methods for evaluating ENM highlighted the importance of using transparent, participatory approaches to move the application of such methods forward (Nel et al., 2013). The benefits and limitations of CEAWeb that we identified in this pilot study thus provide a critical foundation for applying web-based tools to meet the needs for stakeholder engagement in the field of ENM and other emerging areas.

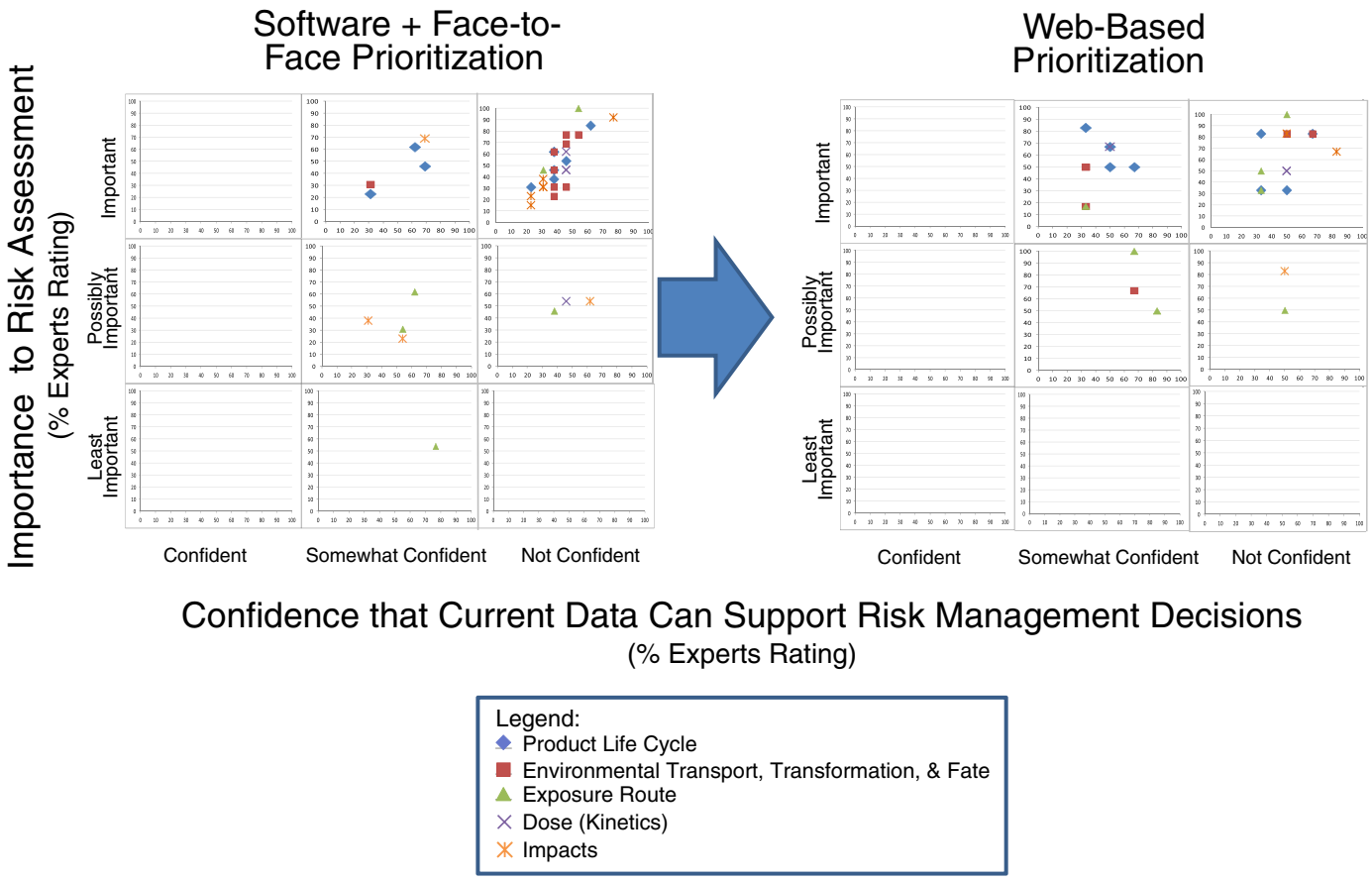

Fig. 4. Identified research priorities. Overview of research priorities identified through engaging stakeholders with a software tool combined with face-to-face discussion (left) compared to those identified in the CEAWeb pilot (right). Data are shown as percentage of participants. See Tables A.3 and A.4 for all data points.

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Disclaimer

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References

Abt E, Rodricks JV, Levy JI, Zeise L, Burke TA. Science and decisions: advancing risk assessment. Risk Anal 2010;30:1028–36.
Grieger KD, Linkov I, Hansen SF, Baun A. Environmental risk analysis for nanomaterials: review and evaluation of frameworks. Nanotoxicology 2012;6:196–212.
Jones R. Public engagement and nanotechnology the UK experience; 2009.
Linkov I, Seager TP. Coupling multi-criteria decision analysis, life-cycle assessment, and risk assessment for emerging threats. Environ Sci Tech 2011;45:5068–74.
Morgan K. Development of a preliminary framework for informing the risk analysis and risk management of nanoparticles. Risk Anal 2005;25:1621–35.
Nel AE, Nasser E, Godwin H, Avery D, Bahadori T, Bergeson L, et al. A multi-stakeholder perspective on the use of alternative test strategies for nanomaterial safety assessment. ACS Nano 2013;7(8):6422–33. http://dx.doi.org/10.1021/nn4037927.
NNI. Environmental health and safety research strategy. Washington, DC: National Science and Technology Council; 2011.
NRC. Public participation in environmental assessment and decision making. In: Dietz T, Stern PC, editors. Washington, DC: National Academies Press; 2008.
NRC. Sustainability and the U.S. EPA. Washington, DC: National Academies Press; 2011.
NRC. A research strategy for environmental, health, and safety aspects of engineered nanomaterials. Washington, DC: National Academies Press; 2012.
OECD. Important issues on risk assessment of manufactured nanomaterials. Series on the safety of manufactured nanomaterials, no. 33, Paris; 2012.
Powers CM, Dana G, Gillespie P, Gwinn MR, Hendren CO, Long TC, et al. Comprehensive environmental assessment: a meta-assessment approach. Environ Sci Tech 2012;46:9202–8.
RTI International. Nanomaterial case study workshop process: identifying and prioritizing research for multiwalled carbon nanotubes. Summary report—final. Research Triangle Park, NC: U.S. Environmental Protection Agency; 2012.
Tervonen T, Linkov I, Figueira JR, Steevens J, Chappell M, Merad M. Risk-based classification system of nanomaterials. J Nanopart Res 2009;11:757–66.
U.S. EPA. Nanomaterial case studies. Nanoscale titanium dioxide in water treatment and topical sunscreen (final), Research Triangle Park; 2010.
U.S. EPA. Nanomaterial case study. a comparison of multiwalled carbon nanotube and decabromodiphenyl ether flame-retardant coatings applied to upholstery textiles (draft), RTP, NC; 2012a.
U.S. EPA. Nanomaterial case study. Nanoscale silver in disinfectant spray (final report); 2012b [Washington, DC].
U.S. GAO. Chemical assessments. An agency wide strategy may help EPA address unmet needs for integrated risk information system assessments; 2013.
Wardak A, Gorman ME, Swami N, Deshpande S. Identification of risks in the life cycle of nanotechnology-based products. J Ind Ecol 2008;12:435–48.